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Memorandum

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AID/OFDA/W

DATE: April 24, 1984

FROM : César Ruiz, ENGRI
USAID/Perú

SUBJECT: Project Adobe Buildings in Seismic Areas - Catholic University
Resumé Paper/Final Report

Please find attached a Resumé Paper of the final report of the Project "Adobe Buildings in Seismic Areas: Innovative Scientific Research" submitted by the Catholic University.

Encl.: a/s

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" SEISMIC STRENGTH OF ADOBE MASONRY"

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SUMMARY

This paper presents the main conclusions and recommendations of the Research Project "Earthen Buildings in Seismic Areas", developed in the Catholic University of Peru (PUCP) in 1983.

The most important soil characteristics from the viewpoint of the strength of adobe masonry are first studied. Subsequently, based on the acquired knowledge, the effect of some natural additives to the soil is investigated. Simple field tests, devised to identify the most adequate materials for adobe construction and to be easily transmitted to the potential adobe builder, are then proposed. Finally, some ideas about the possiblity of disseminating techniques for improved adobe construction in Peru are discussed. These techniques, adapted to local conditions, could be applied to other Third World Countries.

1. INTRODUCTION

Most of the loss of life and material damage caused by earthquakes occur in earthen buildings in Third World Countries. The scientific and technical communities of these countries can significantly contribute to control this problem by finding ways to increase the strength of their traditional buildings and efficient means to disseminate the improved construction techniques among the builders, the majority of whom are impoverished, isolated and culturally destitute. This work intends to be a contribution in that sense.

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2. BACKGROUND AND OBJECTIVES

It was only in the nineteen seventies that consciousness was raised in Peru about the need of studying the problem of seismic strength of adobe buildings. Significant efforts in experimental research were made in the Catholic University of Peru (PUC) and in the National University of Engineering. Initially, research at PUC was oriented towards the study of different types of reinforcement, using rural materials (Refs. 1,2,3 and 4). Subsequently, the effect of some additives in the mortar was studied (Ref.5).

In 1979, PUC and the National Autonomous University of Mexico (UNAM) developed a Joint Research Project to study the strength of adobe masonry. Differences of about 500% in the strength of adobe masonry specimens made with adobe bricks of similar strength were then detected. The cause of such high difference in strength could not be explained at the time.

Most of the research performed on adobe masonry had been based on the study of the relationship between the properties of the materials used and the strength of the adobe brick (Ref.7) and little or no attention was paid to the actual strength of the adobe masonry, which depends mainly on the integration between the adobe bricks and the soil mortar used to join them.

This work aims first to detect and study the soil properties fundamental to the seismic strength of adobe buildings, and then to investigate the effect of some natural additives and construction techniques to improve the strength of these buildings. Another objective is to develop strategies for the dissemination of the obtained results. Some simple constructive recommendations have therefore been developed.

This paper presents only the most important conclusions and recommendations obtained during the Research Project "Adobe Building in Seismic Areas". All the information generated during the research is contained in reference 8, which includes detailed description of the techniques used and the results obtained.

3. SELECTION AND ANALYSIS OF SOILS

Six zones of Peru where adobe construction is traditional were selected for this study. Soil samples from these areas were collected, in order to correlate their physical, chemical and mineralogical characteristics with the seismic strength of adobe masonry made with these soils.

The physical properties of the soils were studied mainly by the evaluation of their granulometric characteristics and their Atterberg Limits. A number of tests were performed to determine the chemical composition of the soils and of water samples brought from each location. The mineralogical characteristics of the clays present in each soil were evaluated through X-Ray diffraction analysis performed at the University of California, Berkeley.

4. SPECIMEN CONSTRUCTION AND MECHANICAL TESTING

In order to guarantee a small dispersion in the test results, especial care was taken in the manufacturing of adobe bricks and masonry test specimens. All masonry specimens were manufactured by the same person. A soil mixer was used to make the soil-water mixture. The workability of all soil mortars was maintained at a standard level, controlled by means of a modified Vicat apparatus (Fig. 1). Both adobe bricks and specimens were dried in the shade, in order to prevent cracking due to drying shrinkage.

After performing a large number of tests with different techniques, the diagonal compression test (Fig. 2) was adopted for the evaluation of the seismic strength of the adobe masonry. The simpler indirect tension test (Fig. 3) was devised in order to conduct preliminary studies, or for cases of limited availbability of material. Other simpler tests, such as the direct tension test were discarded, since they led to unacceptably large dispersion in the results.

The strength of the adobe bricks was evaluated through compression tests on cubes.

The experimental effort of this project consisted of 128 cube compression tests, 509 indirect tension tests, and 246 diagonal compression tests.

5. SIGNIFICANT FACTORS IN SEISMIC STRENGTH OF ADOBE MASONRY

a. Drying Process

One of the most important conclusions drawn from the analysis of the test results is that the strength of adobe masonry greatly depends on the degree of microcracking of the soil mortar due to drying shrinkage. Fig. 4 shows a clear correlation between the volumetric drying shrinkage of adobe bricks -which also indicates the capacity for drying shrinkage of the mortar- and the strength of the masonry. In order to obtain a strong masonry it is therefore indispensable not only to have a material with high dry strength, but also to guarantee the integrity of the brick-mortar ensemble by preventing or controlling microcracking of the mortar.

The study of the drying processes of adobe bricks and mortar was very illustrative in understanding the behavior of the masonry. A correlation was found between the rate of drying and the level of microcracking due to drying shrinkage. This was relatively easy to discover in the case of the adobe bricks, since bricks dried in the shade were significantly less cracked than those dried in the sun.

The drying process of mortar placed between dry adobe bricks occurs in two well defined stages. Most of the microcracking occurs during the first, very rapid stage, due to the sudden loss of mortar water caused by absorption by the drier bricks or to a lesser extent, by the action of gravity. The second stage is much slower; the loss of water is associated basically with evaporation of mortar moisture towards the exterior (Fig. 5).

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This result reveals that any method of exterior curing would be inefficient; conversely, any method which tends to reduce the rate of transfer of water between mortar and bricks would be beneficial in improving the quality of adobe masonry.

b. Material Properties

The characteristics of the soils which have most influence on the strength of adobe masonry are those related either to the shrinking process during drying or to the dry strength of the material.

No correlation was found between the chemical composition of the soils or the water and the strength of adobe masonry.

X-Ray diffraction mineralogical analysis of the clay fractions revealed that adobe masonry strength relates better to the amount than to the type of clay minerals present in the soils.

As expected, granulometric properties of the soils were found to be very important with regard to the seismic strength of adobe masonry.

Soils with high clay content generally have also high dry strength, measured in compression test on cubes carved from adobe bricks. Adobe masonry made with these soils has, however, poor strength, since high levels of microcracking due to drying shrinkage are caused precisely by the presence of clay in the mortar. This phenomenon is apparent in Fig. 6, which shows a seemingly negative correlation between the compressive strength of adobe cubes and the diagonal compression strength of the adobe masonry.

The presence of clay in soils is, however, fundamental to adobe construction, since clay provides for the soil the dry strength, adhesion, plasticity and moisture demand.

No definite relationship was found between the strength of adobe masonry and the silt or sand contents of the soil. Coarse sand content, however, shows a better correlation with strength, due probably to the restraining effect of coarse material, which reduces mortar microcracking due to drying shrinkage.

A standard mortar consistency (or workability), corresponding to 10 mm penetration in the modified Vicat apparatus, was maintained throughout the research. It was observed that in general, stronger masonries required less water in the mortar in order to reach the standard consistency. The water content for standard consistency is therefore a characteristic parameter of the soil. This parameter, which evaluates the plasticity of the soil and is also a measure of the adhesion between mortar and brick, does not have good correlation with the ability to restrain microcracking due to drying shrinkage, which is governed by the coarse material.

Atterberg Limits are essentially useful for standard soil classification. Unfortunately, they are not good indicators of the seismic strength of adobe masonry. For instance, the Plasticity Index is computed using only the soil fraction smaller that # 40 mesh, and not with all the soil; therefore its value does not necessarily reflect the actual plasticity of the soil used for adobe construction.

c. Effect of some additives

In general, the addition of agglutinant agents to the soil was not very efficient in improving the strength of the adobe masonry. Addition of lime actually decreased the strength of the masonry. Addition of cement -in amounts larger than 10% and mixed with sand- led to some increase in strength. Previous research had shown that addition of a mixture of cement and sand to mortar only, is advantageous. (Ref. 5).

Small amounts of sodium carbonate, a dispersive agent, led to some increase in the compressive strength of adobe bricks.

Addition of small amounts of manure to the mortar increased masonry strength, since fibers in manure help restraining growth and propagation of microcracks in the mortar. Larger amounts of manure led to smaller strengths due perhaps to the presence of organic matter or other components.

d. Construction Process

Quality of workmanship plays an important role in obtaining a strong adobe masonry. For instance, diagonal compression tests made with specimens built with traditional techniques showed a strength of 0.23 Kg/cm^2, whereas than samples - built with high quality of workmanship resisted 0.47 Kg/cm^2 (Refs. 6 and 8).

Masonry quality was noticeably improved by wetting the adobe bricks, letting them sit for approximately 10 minutes in a container with 1 cm of water, before placing the mortar. This procedure reduced microcracking and improved mortar - brick integration. The use of dry but workable mortars was found to be advantageous, since the number and width of cracks due to drying shrinkage were reduced. (Fig. 7).

It was also found that adobe bricks attained sufficient strength to be manipulated one week after their manufacturing and that the strength of adobe masonry stabilizes at about two weeks after fabrication.

The positive effect of "sleeping" the mud (storing it for one or two days) before the fabrication of adobe bricks or mortar, a traditional practice in Peru, was confirmed. It seems that this procedure allows for a better dispersion and thus for a more uniform action of clay particles.

6. IMPROVEMENT OF ADOBE MASONRY

Based on the results described above, it was decided to attempt improving the strength of adobe masonry by reducing the level of microcracking of the mortar - through:

a. Restrain of drying shrinkage by addition of coarse sand to the natural soil.

b. Control of growth and propagation of crakcs by addition of straw to the mortar.

c. Reduction of the drying rate of the mortar by decreasing the difference in

moisture between brick and mortar.

The effect of the addition of coarse sand (size of particles comprised between # 4 and # 40 mesh) to the six selected soils was investigated. The amounts added varied between 30 and 300% in volume. Sand was added in some cases to both mortar and bricks, and in other cases only to the mortar. In both instances the drying process, the degree of microcracking of the mortar and the strength of the masonry were studied. Additionally, the effect of previous wetting of the adobe bricks was investigated.

Addition of coarse sand led, in general, to a decrease in the number and average width of the cracks in the mortar (Fig. 8), to a better integration between mortar and brick, and to a significant increase of the strength of the masonry, especially in the cases where the natural soil had a high clay content (Fig. 9, notice Cajamarca and PUC soils). It was found that there is an optimum amount of coarse sand, corresponding to the elimination of the visible cracks in the mortar (Fig. 10). Smaller amounts of coarse sand produced mortars with excessive cracking; addition of larger amounts of sand led to masonry with poor strength due to the decrease in clay content (clay provides the dry strength).

Addition of coarse sand also affected the type of failure observed in the specimens tested. In most of the specimens made with natural soils, the cracks followed the mortar-brick joints. When coarse sand was added to the soil, the cracks also cut the adobe bricks, showing the loss in strength of the bricks due to the diminution of clay. This phenomenon was corroborated with compressive tests of cubes (Fig. 11).

Two types of straw were used as additives: common grass leaves about 5 cm long, and "ichu", a straw from the Andes, chopped in pieces of about 10 cm in length. Some of the traditional Peruvian techniques for the manufacturing of adobe bricks call for the addition of straw to the soil in percentages smaller to 0.5% in weight. The amounts of straw used in this investigation varied between 0.5 to 8%. The effect of addition of straw on mortar workability and strength of adobe masonry were studied.

Addition of straw was found to be even more efficient than addition of coarse sand in improving the strength of adobe masonry. (Compare Figs. 10 and 12). Practically the same results were obtained with both types of straw. The increase in strength can be explained by the "sewing" action of the brick-mortar interface produced by the straw fibers in the mortar. This effect helps to improve the integration, and thus the strength of adobe masonry. The compressive strength of the brick was not found to decrease, as in the case of addition of coarse sand. However, the water demand of the mortar to reach an adequate workability increased with the addition of straw. Therefore, addition of very large amounts of straw is not convenient. The optimum amount to be added to a given soil is then controlled by the workability of the soil-straw-water mixture used to make the adobes and mortar.

Simultaneous addition of coarse sand and straw was not efficient in improving the strength of adobe masonry.

Full-scale shear tests on adobe walls were performed to corroborate the observed beneficial effects of addition of coarse sand or straw to the natural soil.

Fig. 13 shows the test set-up. The improvement of strength obtained was in this case of the order of 100%, with respect to walls made with natural soil (see Fig. 14). This implies an increase in strength of the order of 400% with respect to traditional adobe masonry.

7. CONCLUSIONS AND PRACTICAL RECOMMENDATIONS

The main conclusions drawn from this investigation regarding the seismic strength of adobe buildings are:

- The most important component of the soil is clay, since it provides dry strength. Unfortunately, clay also causes drying shrinkage of the soil.

- In order to obtain strong adobe masonry, it is indispensable to control the microcracking of the soil mortar due to drying shrinkage.

- Straw and, to a lesser extent, coarse sand are efficient natural additives which can be used to control microcracking of the mortar due to drying shrinkage, and therefore to improve the quality of adobe masonry.

Based on these conclusions, the following practical recommendations were established in order to select adequate soils and additives, and to improve the construction techniques to obtain stronger adobe buildings.

a. Procedure for Selection of Materials

- Select an available soil, as a candidate for adobe construction.

- Perform the dry strength test, consisting of making three or more little balls (of about 2 cm diameter) of mud make of the selected soil. Once dry after at least 24 hours each ball is crushed between the thumb and the index fingers. If all balls are so strong that none can be broken, the soil has enough clay to be used for adobe construction, provided that microcracking of the mortar due to drying shrinkage is controlled. If some of the balls can be crushed, the soil is inadequate, since it lacks clay and should be discarded.

- Add to the mud, especially when preparing the mortar, the maximum amount of straw which allows for an adequate workability.

- If straw is not available, perform the microcracking control test. This test consists of making two or more sandwiches (two adobe bricks joined with mortar) using existing adobe bricks and mortar made with the soil under study. After 48 hours of drying in the shade, the sandwiches are carefully opened and the mortar examined. If the mortar does not show visible cracking, the soil is adequate for adobe construction. Otherwise, use coarse sand (0.5 to 5 mm aprox.) as additive to control microcracking due to drying shrinkage. If coarse sand is unavailable the soil should be discarded.

- The most adequate soil-coarse sand proportion is determined by performing

again the microcracking control test with at least eight sandwiches made with mortars with different proportions of soil and coarse sand. It is recommended that the soil:coarse sand proportions vary between 1:0 (no sand) to 1:3 in volume. The sandwich with less amount of sand which shows no visible cracking after opening 48 hours after manufacturing indicates the soil: coarse sand proportion to be used for adobe construction.

b. Construction Process

Some constructive recommendations drawn from the experience acquired during this investigation are:

- To wet the adobe bricks before laying, putting them over about 1/2 to 1cm of water, or to moisten them by any equivalent procedure. At least the two horizontal faces should be wetted for 10 to 15 minutes.

- To use the bricks as soon after manufacturing as they are able to be manipulated, since the more humid bricks will be less prone to absorb water from the mortar.

Other general recommendations which should be mentioned in this report are : to eliminate all foreign matter from the soil, to mix the mud as thoroughly and uniformly as possible, to dry the adobe bricks in the shade, to clean the bricks before laying, to make uniform and complete mortar joints, and to check the verticality of the walls.

8. DISSEMINATION STRATEGIES FOR ADOBE TECHNOLOGY

In order to reformulate the ideas about dissemination of technology for adobe construction, a team of sociologists and anthropologists from PUC developed field surveys in three urban and four rural zones in Peru.

It was found that, in general, it is not possible to define any one solution to the problem, since the dissemination possibilities are extremely varied and seem to complement each other, and in every case, they would depend on the local conditions. Nevertheless, the following general recommendations could be reached:

a. Urban Zones

Within the urban context, the adobe construction is used mainly in the so-called "Pueblos Jovenes" (Young Towns) or shanty towns around the main cities or in the smaller cities. Adobe dwellings are generally regarded as signs of low economic and social status. The dissemination methodology seems to be uniform, since it would be oriented towards a basically literate public.

Masons are usually employed to build the adobe houses, therefore the dissemination programs should be geared mainly towards improving the level of acceptance in the communities of construction with adobe based on a better, innovative technology. The proposed dissemination methods are:

- Radio and television programs, complemented with a system of consultation by

mail.

- Courses for adobe masons. Distribution of a specialized booklet. Institutionalization of some kind of official certificate for qualified masons.

- Communal courses in adult schools, technical schools, neighborhood associations, etc. Distribution of a "popular" booklet.

b. Rural Zones

In rural zones, construction with adobe is performed either by the dwellers or by communal work. The dissemination methodology seems to be in these cases more varied, since it would depend on the organization and traditional customs of each particular community. The following alternatives are proposed:

- Courses for adobe masons and for the general public through Agricultural or Cooperative Associations, developed in co-ordination with existing educational programs. Distribution of technical booklets.

- Radio Programs.

- Distribution of simple technical booklets through governmental, religious or educational institutions.

It seems that the most effective dissemination of improved adobe construction technology could be performed in places with high construction potential. Particularly, it would be especially convenient to develop accelerated educative programs in rehabilitation zones after natural disasters.

ACKNOWLEDGEMENTS

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Many thanks are due to Research Assistants Gladys Villa-Garcia and Juan Ginocchio for their effort and dedication, and to the personnel of the Earthquake Engineering Laboratory of the Catholic University of Peru.

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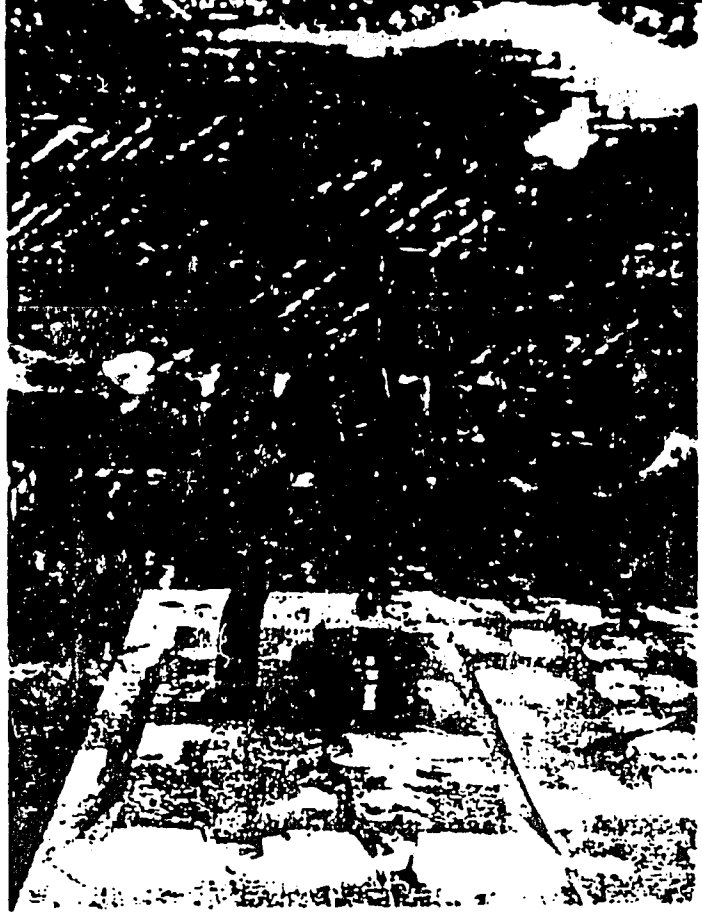

FIG.1 MODIFIED VICAT APPARATUS

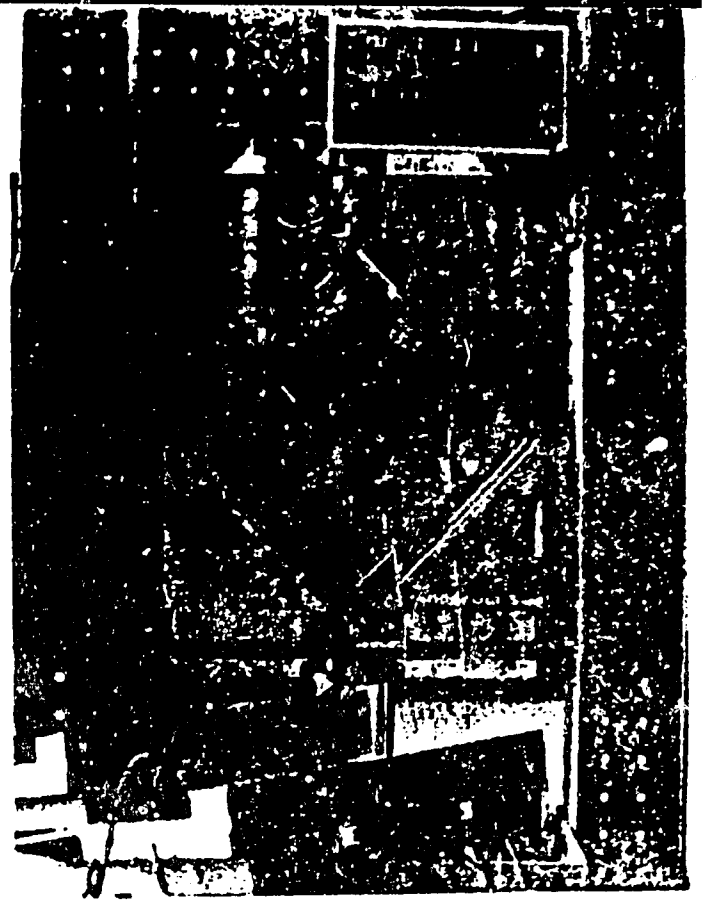

FIG.2 DIAGONAL COMPRESSION TEST

FIG.3 INDIRECT TENSION TEST

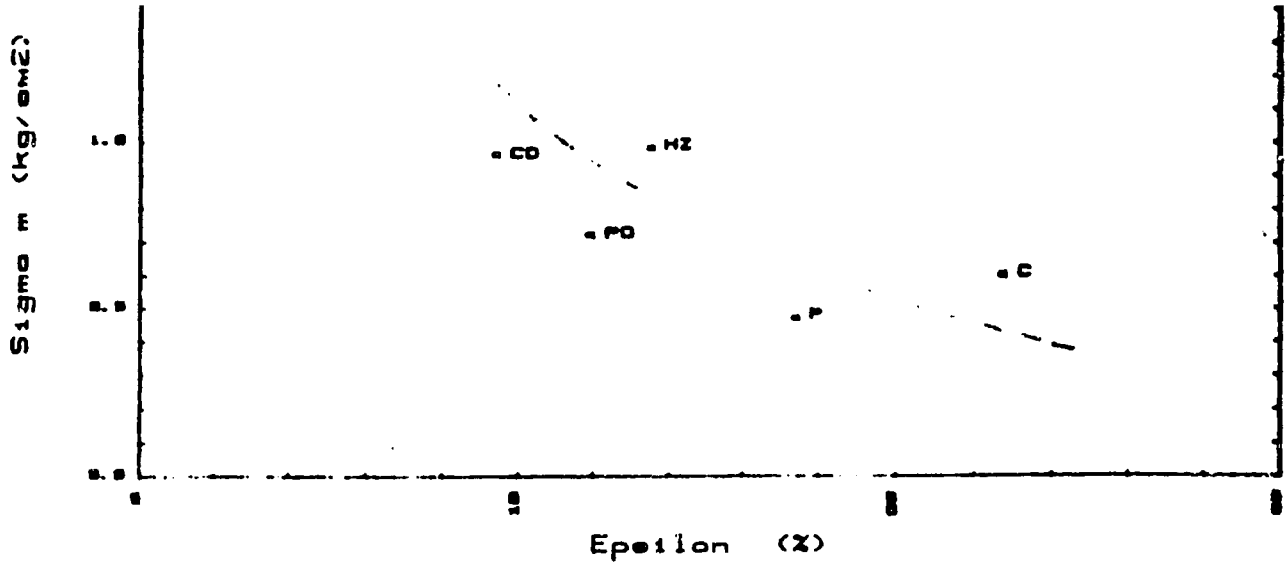

Fig. 4 DIAGONAL COMPRESSION STRENGTH vs VOLUMETRIC SHRINKAGE OF BRICK

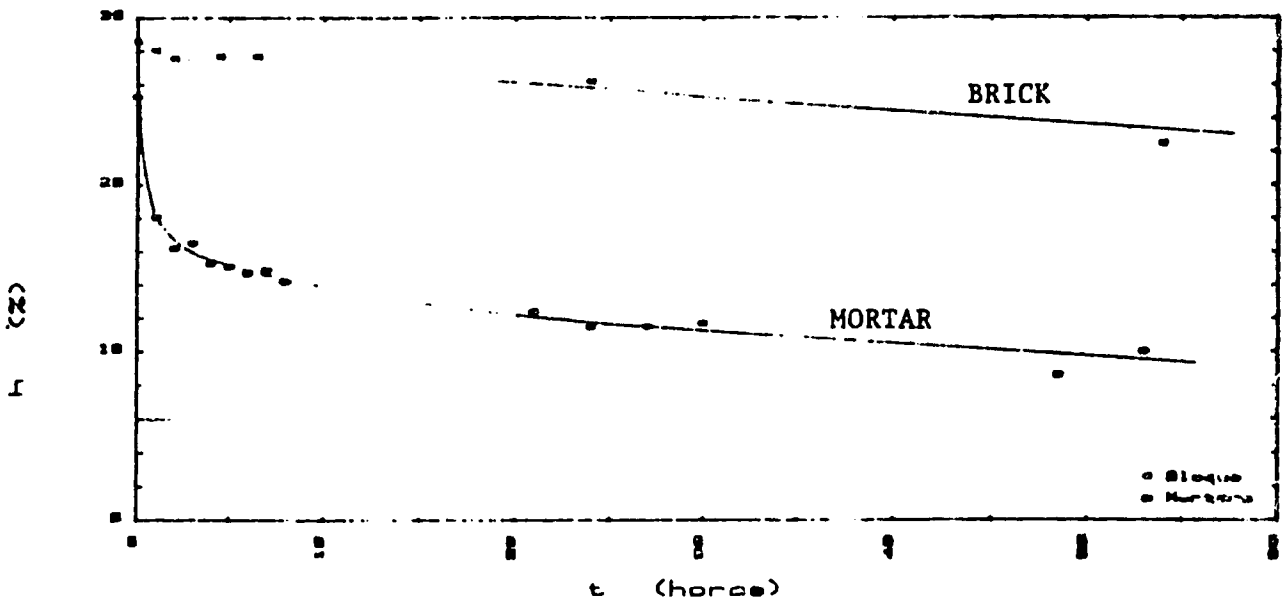

Fig. 5 WATER CONTENT vs TIME

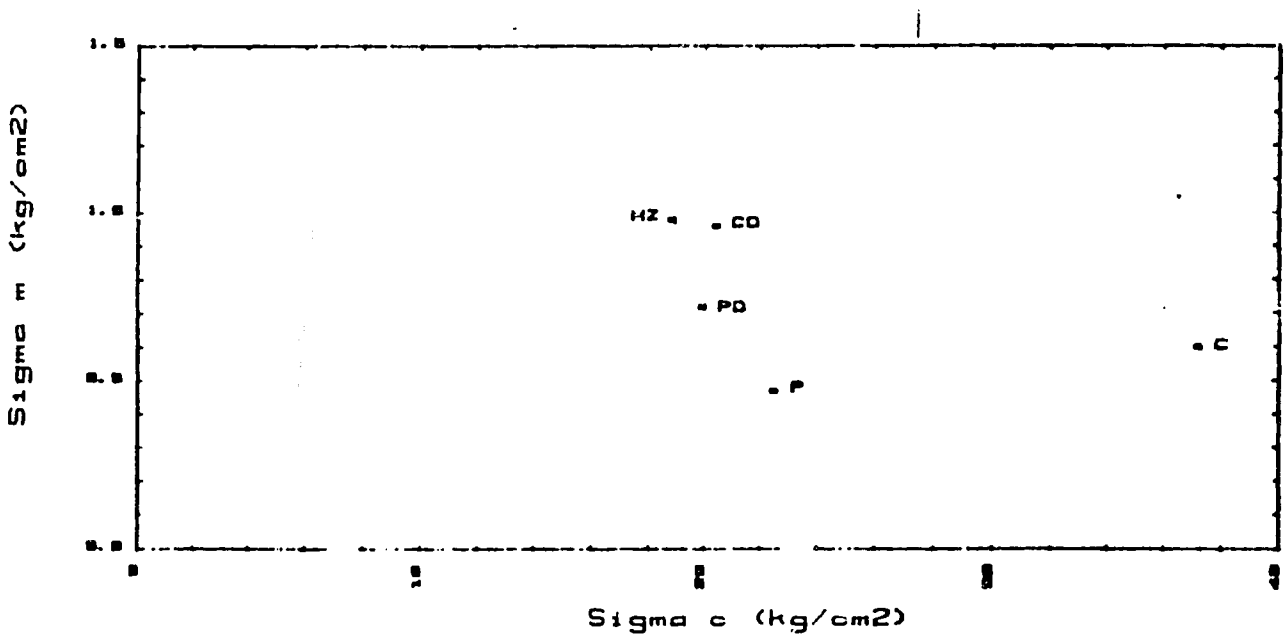

Fig. 6 DIAGONAL COMPRESSION STRENGTH vs COMPRESSIVE STRENGTH OF BRICK

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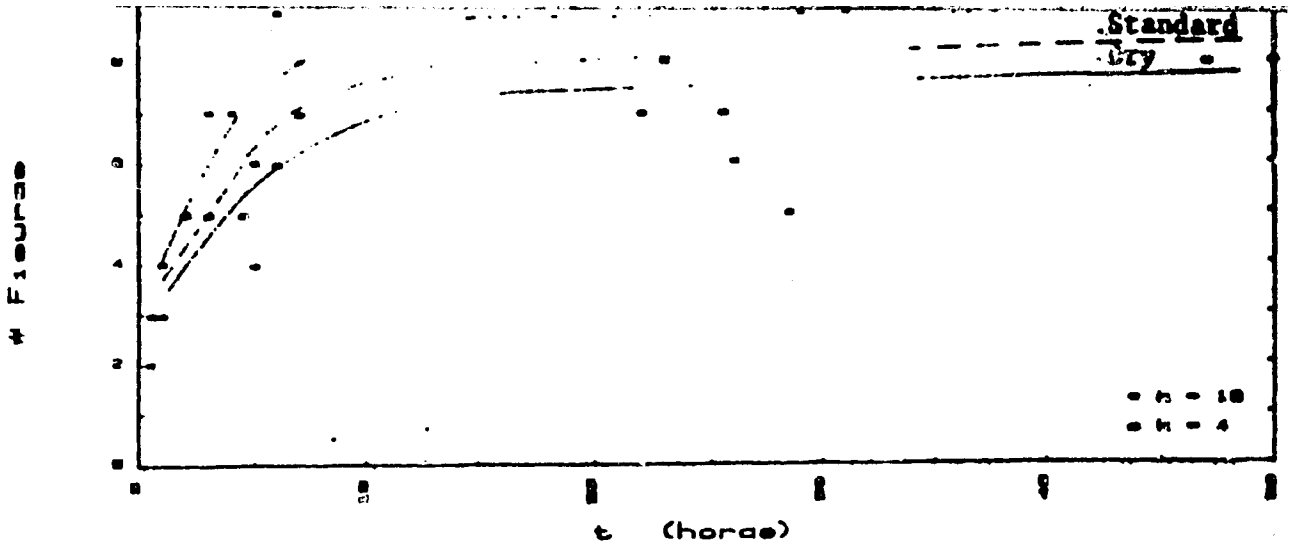


Fig. 7 AVERAGE NUMBER OF CRACKS vs TIME
Effect of Initial Consistency of Mortar

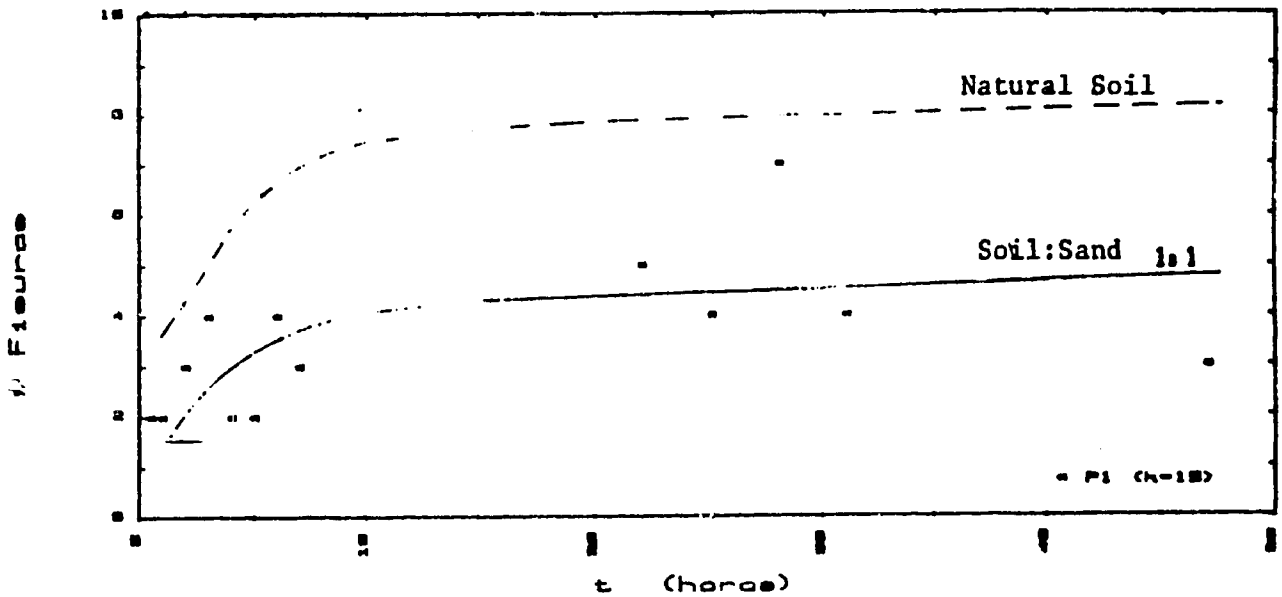


Fig. 8 AVERAGE NUMBER OF CRACKS vs TIME
Effect of Addition of Coarse Sand to Mortar

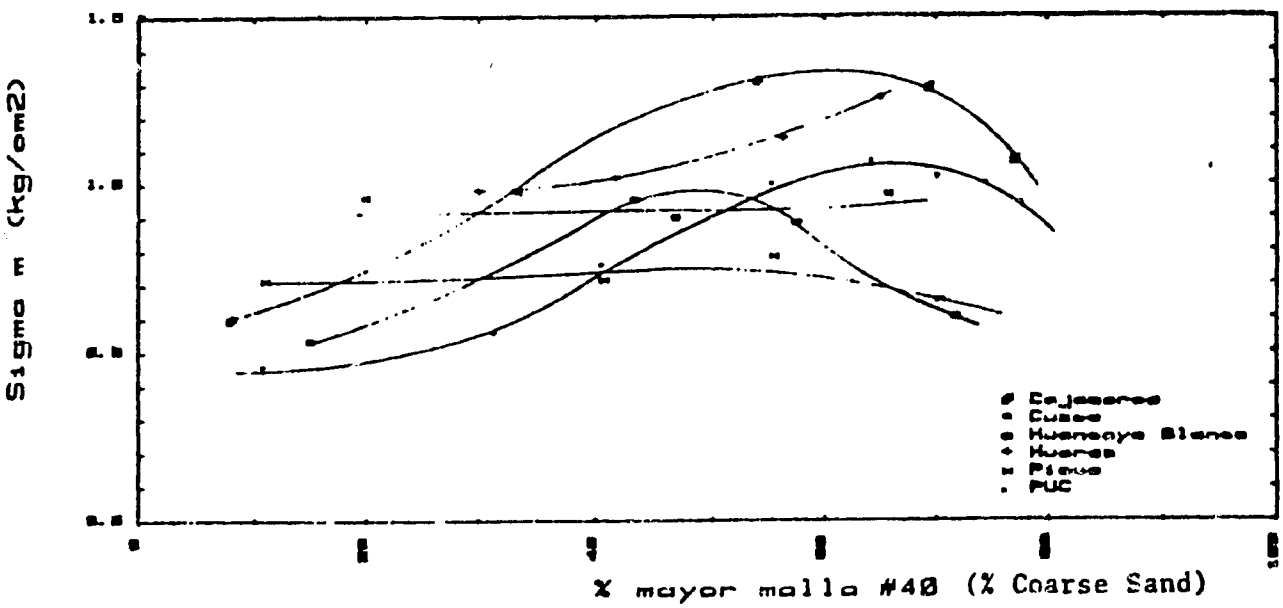


Fig. 9 EFFECT OF ADDITION OF COARSE SAND TO MORTAR IN DIAGONAL COMPRESSION STRENGTH

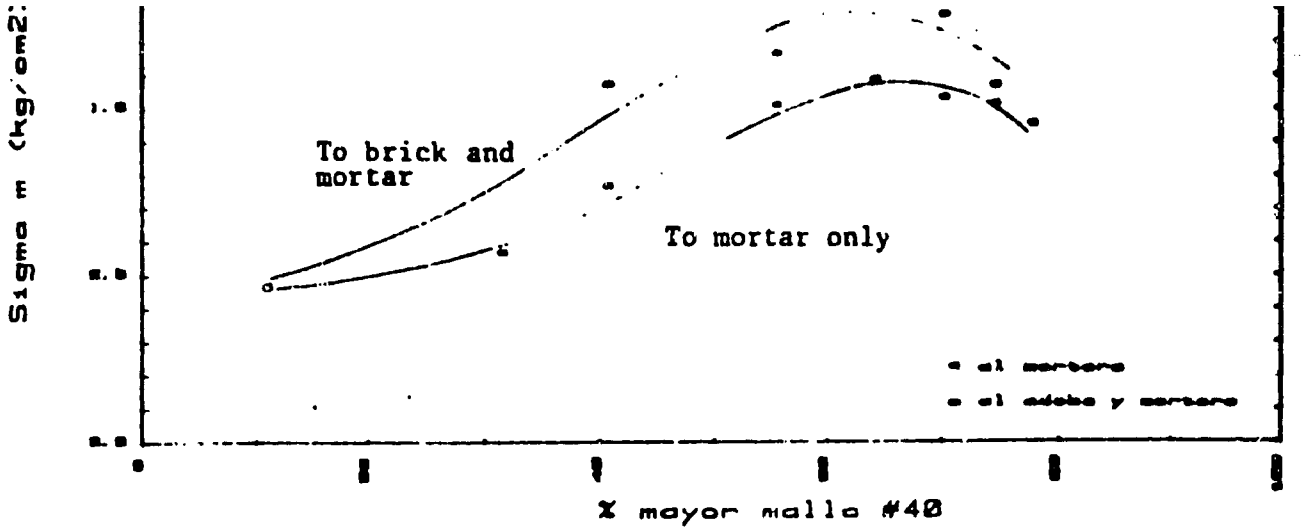


Fig. 10 EFFECT OF ADDITION OF COARSE SAND TO PUC SOIL

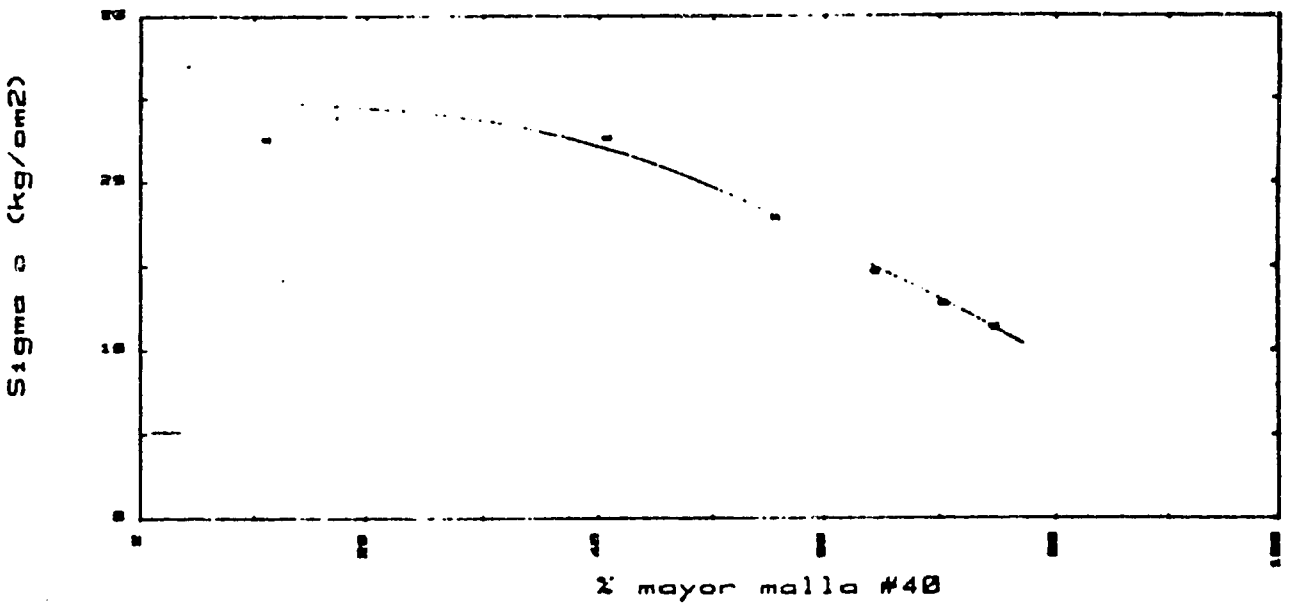


Fig. 11 EFFECT OF ADDITION OF COARSE SAND IN COMPRESSIVE STRENGTH OF BRICK

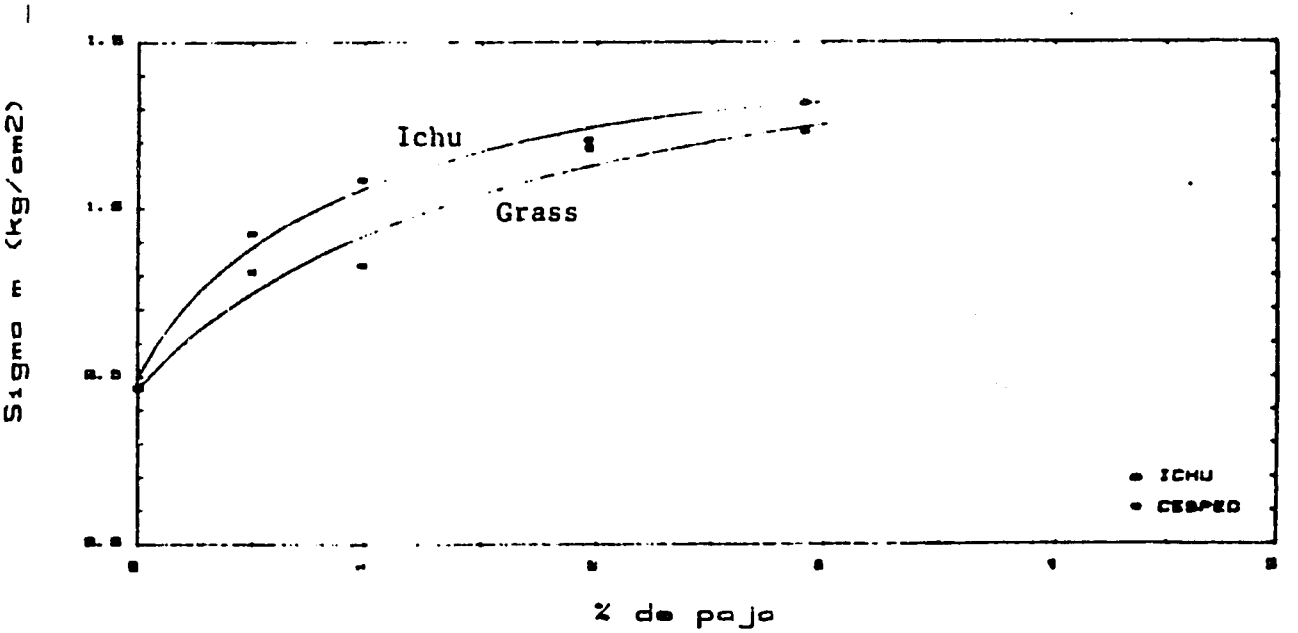
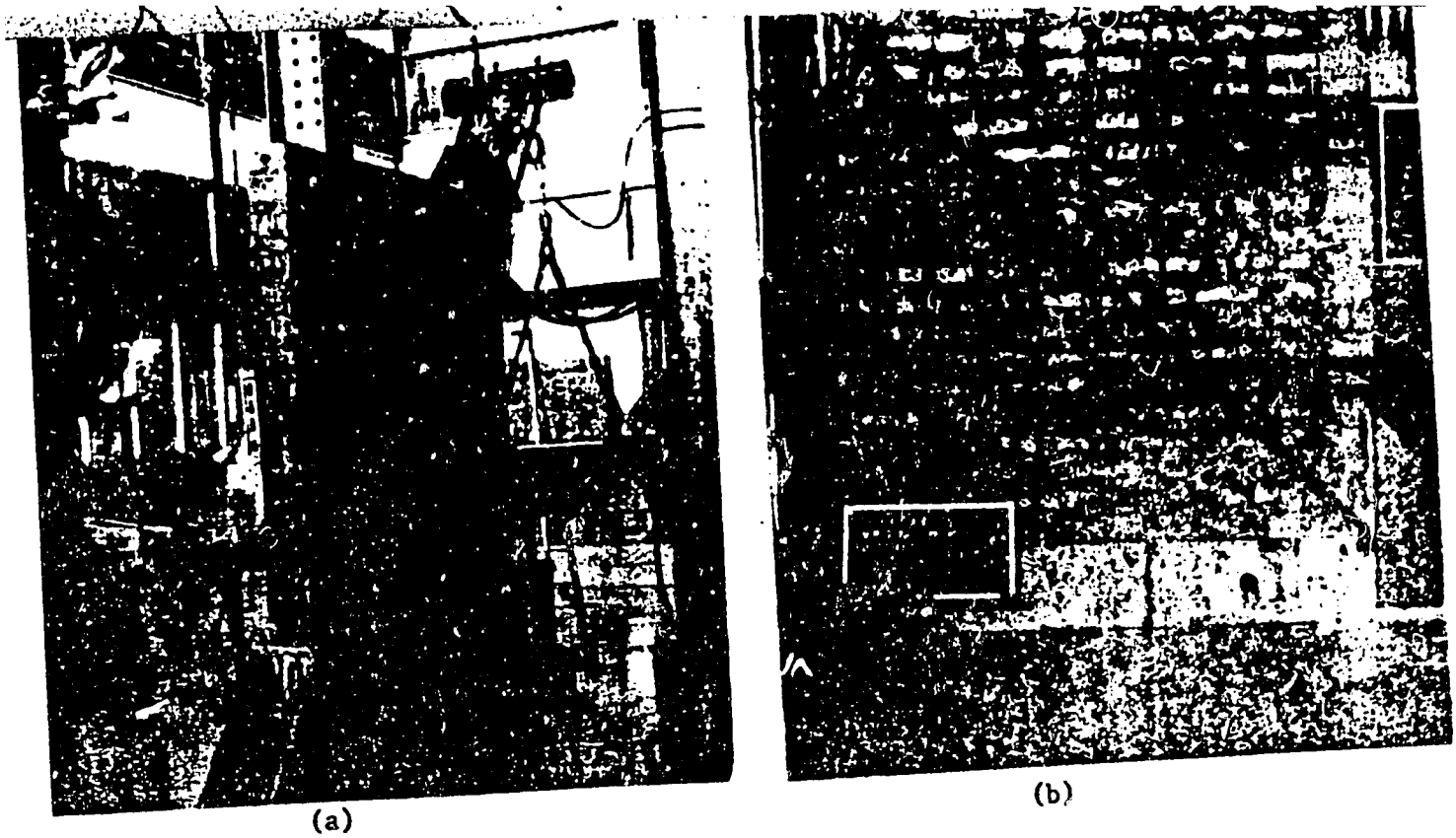


Fig. 12 EFFECT OF ADDITION OF STRAW TO PUC SOIL



(a) (b)

FIG.13 SHEAR TESTS ON FULL SCALE WALLS

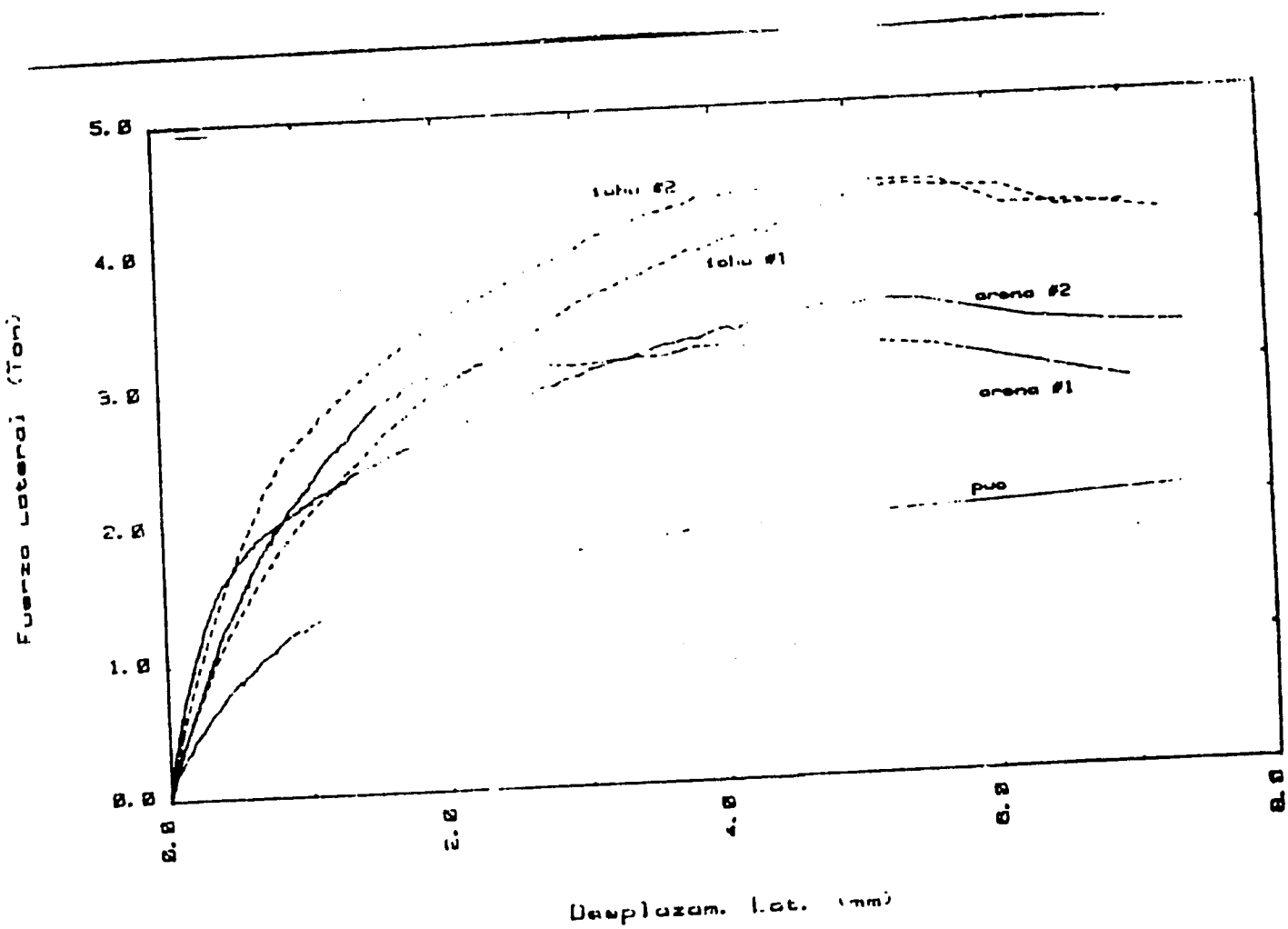


FIG.14 FULL SCALE WALL TEST RESULTS